Mars Exploration Rover Project

Mars Express Orbiter - Mars Exploration Rover Relay Link Interface Control Document Part 1. RF and Proximity-1 Compatibility

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1 Introduction

1.1 Scope

This document specifies the interface for the transfer of data between the Mars Exploration Rovers (MER) and the Mars Express (MEX) Orbiter transceivers, that will serve as a communication relay during the rovers surface operations on the Mars surface. It also serves as a commitment between the two Projects to perform the described tests.

Part 1 of this document specifies the telecommunications interface (transfer of data in the Proximity link between the two transceivers), while Part 2 details the end to end data flow interface between the two projects, including the ground system.

1.2 Applicable Documents

- Melacom Users Requirements Specifications, MEX-EST-RS-5010, July 2000

1.3 Reference Documents

- Proximity-1 Space Link Protocol, CCSDS 211.0-R-2, January 2000
- Packet Telemetry, CCSDS-102.0-B-5, November, 2000.
- Rosetta/Mars Express Mission Control System Command Request Interface Document RO-ESC-IF-5004/MEX-ESC-IF-5004.

2 Specifications Relative to Proximity-1 Link Protocol

2.1 Physical Layer

2.1.1 Frequencies

- Single forward and return frequencies
- Forward frequency 437.1 MHz
- Return frequency 401.585625 MHz
- Hailing frequency 437.1 MHz

2.1.2 Modulation

- PCM/Bi-Phase-L/PM
- Residual Carrier with a modulation index of 60° (±10% for MER, ±5% for MEX)

2.1.3 Data Rates

- Forward 8 kbps
- Return 8, 32, 128 kbps

2.1.4 Convolutional Encoding

- Return link only
- Rate 1/2 with constraint length 7, non-inverted G2 polynomial

2.1.5 Carrier Frequency Stability Requirement

- MER 2 ppm over temperature, 1 ppm for aging per year
- MEX 0.001 ppm over temperature, 0.01 ppm for aging per day

2.1.6 Doppler Tracking

- MER Carrier acquisition ±6 kHz, carrier tracking ±12 kHz
- MEX ±16 kHz

2.2 Data Link Layer

2.2.1 Link Establishment

- MEX will establish the link with the following sequence in the forward link:
    - 5 sec CW + 4096 idle bits + SET DIRECTIVE + 5 sec CW + 4096 idle bits. Idle bits are defined as alternating 1s and 0s
  - MER responds with 1second of CW followed by 4096 idle bits
  - If the signal from MER is not acquired by MEX within **5** sec from the transmission of the SET DIRECTIVE, MEX stops transmitting for 2 seconds before restarting the link establishment cycle.
    - For MER the link is declared established when bit synch lock is achieved.
    - For MEX the link is declared established when carrier and bit sync lock are achieved.

2.2.1.1 SET DIRECTIVE

The SET directive has the following format

	ASM	*Header*	*Data Field*	*CRC*
Directive PDU	3 bytes	5 bytes	5 bytes	4 bytes

	PDU Type	*PDU Subtype*	*Length*	*Set TX Directive*	*Set RX Directive*
Data Field, bits	0,1='00'	2,3='00'	4-7='0100'	8-23	24-39

Figure 1. SET Directive PDU

The Set Transmitter and Set Receiver directives have a common structure as shown in Figure 2, where the specific commands (set mode, data rate, etc…) will be effective, on the receiver or transmitter portion of the MER transceiver, based on the 3 bits of the Directive Type field (bits 13-15): '000' indicates a Set Transmitter directive, '010' indicates a Set Receiver directive.

Mode	*Rate*	*Modulation*	*Encoding*	*Frequency*	*Directive Type*
0,1,2	3,4,5,6	7	8,9	10,11,12='000'	13,14,15

Figure 2. Set Transmitter and Set Receiver Directives

The frequency field is always set to '000' by MER. Frequency field is not checked by MER in reception (frequency are fixed at 437.1 MHz for forward link, 401.585625 MHZ for return link).

Tables 1 and 2 define the valid settings of parameters based on the value of bits 0-9 in the Set Directive.

Table 1. Set TX Directive Sent by MEX to MER

TX Mode	**TX Data Rate**	**TX Modulation**	**TX Coding**
001=Sequence Controlled	0000=8 KBPS	1=PSK non coherent	01= Convolutional non inv. G2
010=Expedited Mode	0010=32 KBPS		10=Bypass Coding
	0100=128 KBPS		

Table 2. Set RX Directive Sent MEX to MER

RX Mode	**RX Data Rate**	**RX Modulation**	**RX Coding**
001=Sequence Controlled	0000=8 KBPS	1=PSK non coherent	
010=Expedited Mode			10=Bypass Coding

2.2.2 Proximity Link Transmission Unit (PLTU)

- A PLTU consists of a Transfer Frame with attached ASM and CRS as shown in Figure 3.
- The Attached Synchronization Marker (ASM) consists of the 24 bit sequence FAF320'h
- The CRC is 32 bits long and is generated using the generator polynomial

$$x^{32} + x^{23} + x^{21} + x^{11} + x^{2} + 1$$

PLTU

ASM	*Transfer Frame*	*CRC*
3 bytes	up to 1024 bytes	4 bytes

Transfer Frame

Header	*Data Field*
5 bytes	up to 1019 bytes

Header

	Version Number	*QoS*	*PDU Type ID*	*Data Field Construction ID*	*S/C ID*	*VC ID*	*Port ID*	*Source Destination Flag*	*Frame Length*	*Frame Sequence Number*
bits	0,1	2	3	4, 5	6-15	16	17-19	20	21-31	32-39

Figure 3. Format of the Proximity Link Transfer Unit, of the Transfer Frame and its Header

2.2.3 Frame Header

2.2.3.1 Version Number

- Fixed Value ‘10’

2.2.3.2 Quality of Service

- Sequence Controlled ('0')
- Expedited Service ('1')

2.2.3.3 PDU Type ID

- User Data ('0')
- Protocol Data ('1')

2.2.3.4 Data Field Construction ID

- User Defined Data ('11')

2.2.3.5 SCID

- MER1-Flight Operations FD'hex
- MER2-Flight Operations FE'hex
- Simulations, Testbed FC'hex and FF'hex
- SCID is always verified upon reception of frames for the sequence controlled service

2.2.3.6 Virtual Channel ID

- '0' is sent in return link frames by MER, ‘1’ is sent in forward link by MEX
- MER and MEX do not check VC in reception

2.2.3.7 Port ID

- '000' (MER does not care in reception)

2.2.3.8 Source or Destination ID

- '0' for Return link, '1' for Forward link

2.2.3.9 Frame Length

- Variable up to 1024 bytes (not including ASM or CRC)

2.2.3.10 Transfer Frame Data Field

- Variable up to 1019 bytes

2.2.3.11 Frame Sequence Number

- The frame sequence number will be incremented monotonically during a relay session (sequence controlled service only).
- The frame sequence number will be set to zero at the beginning of a relay session.
- The frame sequence number is not checked in the expedited service.

2.2.3.12 Transfer Frame Data Field

- The data field contains user defined data (a bit stream) of variable length up to 1019 bytes.

2.2.4 ARQ Protocol

In the sequence controlled service, MER uses a Go-Back 2 protocol; MEX a Go-Back 128 protocol.

Retransmission request are handled by the Proximity Link Control Word explained below

For MER the transmission window is set to two frames. Frames are retransmitted if acknowledgments are not received within the two frame transmission time.

For MEX the transmission window is set to 127 frames.

	PDU Type	*Retransmit Flag*	*VC ID*	*Spare*	*Expedited Frame Counter*	*Report Value*
Data Field	0,1='10'	2	3='0'	4='0'	5,6,7='000'	8-15

Figure 4. PLCW Structure

– Retransmit Flag, bit 2, is set to '1' when retransmission is required for any of the previously received frames
  - For PLCW transmitted by MEX this flag will set when N(S) > V(R) i.e., when the sequence number received exceeds the count expected by the receiver; N(S) < V(R) (frame already received), invalid Spacecraft ID, an invalid CRC-32 decode are not conditions for retransmission
  - MER will not check this flag in reception of a PLCW; frames retransmission will be assessed based only on report value field (see below) of the PLCW
  - For PLCW transmitted by MER this flag will set when N(S) > V(R) i.e., when the sequence number received exceeds the count expected by the receiver and when N(S) < V(R) (frame already received); invalid Spacecraft ID, an invalid CRC-32 decode are not conditions for retransmission
– Virtual Channel ID field, bit 3, is always '0' (no support for multiple VCs, MER does not care in reception)
– Expedited Frame Counter is always set to '000' (MER does not care in reception)
– Report Value Field, 8 bits, contains the next expected frame sequence number (0-255).

3 Relay Link Performance

3.1 MER

- All power levels are specified at the common port of the diplexer
- RF Power > 40.0 dBm
- Receive Threshold < -116 dBm (8 kbps uncoded, BER=1E-6)
- Carrier Acquisition = ±6 kHz for received power >-116 dBm
- Carrier Acquisition Time < 1 sec
- Circuit Loss = 0.4 dB
- Antenna Gain: monopole linearly polarized - see figure 5 for flight unit pattern measurement on a mockup of the rover. Data Tables with the antenna patterns are available for link analysis.

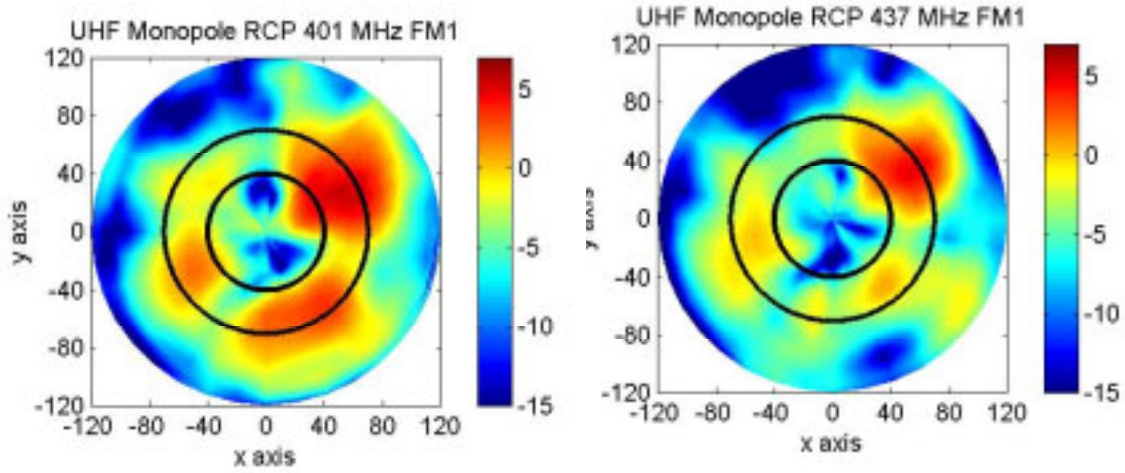

Figure 5. MER Antenna Pattern (in dBic at 401 and 437 MHz) measured on a mock-up of the rover.

3.2 MEX

- All power levels are specified at the transceiver input and output ports
- RF Power > 36 dBm
- Receive Threshold < -124.0 dBm (8 kbps coded, BER=1E-6)
- Receive Threshold < -112.0 dBm (128 kbps coded, BER=1E-6)
- Carrier Acquisition =-133 dBm; ±16 kHz
- Carrier Acquisition Time < 1 for received power > -115 dBm
- Circuit Loss = 0.5 dB
- Antenna Polarization: Right Hand Circular

- Antenna Gain: 6 dBi (TBC) on boresight; -2 dBi @±50°; -10 dBi@±65°
- Antenna Axial Ratio: TBS

4. Data Format

This section specifies the format of the data to be used in the return and forward links. More details are contained in Part 2 of this document, including the interface of the ground system of the two projects. In order to assure compatibility, the scope of the specification in Part 1 is to assure that the flight system on MEX is not imposing any constraint on the format of the data to be sent on the proximity-1 link.

4.1 Return Link Data Format

To demonstrate the return link, MEX shall be able to accept an unpacketized bitstream from MER A or B via the UHF link. MEX shall be able to transmit this bitstream to Earth.

On the return link, the MER Rover will send bit stream data in proximity-1 frame to MEX through UHF link. MEX, upon receipt of each proximity-1 transfer frame, will validate the transfer frame then remove the proximity-1 transfer frame header and CRC coding.

Melacom reformats data received from a lander to ensure that these three requirements are met. This reformatting involves the addition of a header to the lander data, and the concatenation of small data blocks received over the proximity-1 link. The header is of variable length and is formatted as follows:

Header					***Data***
CCSDS packet header	***Time stamp***	***Data field header***	***Fill length***	***Fill***	
Standard CCSDS telemetry packet header APID assigned by telecommand	32 bits coarse time (seconds) 16 bits fine time (subseconds)	Fixed: 00 14 0D 00	0, 1, 2 or 3	55_{16} repeated as necessary	Data field of one or more proximity-1 frames
		Indicates that this packet contains science (i.e. lander) data	indicates number of fill bytes following		
48 bits	48 bits	32 bits	8 bits	0, 8, 16 or 32 bits	Usually >1024 bytes

Ground based data extraction routines must be able to cope with removal of this variable length header.

4.2 Forward Link Data Format

To demonstrate the forward telecom link, MEX MOC shall be able to accept file containing a MER command load file from MER Operations and send it to MEX. MEX shall then be able to forward this bitstream to MER A or MER B.

5. RF Compatibility Verification

5.1 RF and Proximity Protocol compatibility

This effort is anticipated to include two tests. These will verify the capability of establishing a compatible proximity link and the capability of transferring data in the proximity link.

The initial RF compatibility test was conducted using the MER Engineering Development Unit (EDU) and the MELACOM flight spare model in August 2002. This testing included exercise of all of data rates that are compatible with both the rovers and MEX.

The MER-MEX UHF compatibility test will use the MER flight unit UHF radio integrated with the MER flight system in the ATLO environment. It is desirable to bring a MELACOM engineering model to JPL for this test. The date of this test is planned to be in January 2003. The actual duration for this test is 3 days. It is estimated that the equipment set up and take down will take 2 additional days. Support to set up the MELACOM test unit, to operate it during the test, and to take down the equipment is needed from ESA.

Appendix B: Acronyms List

APID	Application Packet ID
ARQ	Automatic Repeat Request
ASM	Attached Synchronization Marker
BER	Bit Error Rate
CCSDS	Consultative Committee for Space Data Systems
CRC	Cyclic Redundancy Code
CW	Continuous Wave
DSN	Deep Space Network
EDAC	Error Detection and Correction
FECW	Frame Error Control Word
FER	Frame Error Rate
GDS	Ground Data System
MEX	Mars Express Orbiter
MER	Mars Exploration Rover
PDU	Protocol Data Unit
PLCW	Proximity Link Control Word
PLTU	Proximity Link Transfer Unit
PSK	Phase Shift Keying
QoS	Quality of Service
RHCP	Right Hand Circular Polarization
RS	Reed Solomon
SCID	Spacecraft ID
TBC	To Be Confirmed
TBS	To Be Supplied
UHF	Ultra High Frequency
VC	Virtual Channel